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THE FIRST HALLEY LECTURE
DELIVERED BEFORE THE UNIVERSITY
ON TUESDAY, MAY 10, 1910

BY

HENRY WILDE, D.Sc., D.C.L., F.R.S.

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A COMBINATION of interesting circumstances brings me to-day before the members of the University to discourse on an important feature of celestial mechanics which has not hitherto been treated as a generalization drawn from observations on the great scale of nature.

While the principle of dualism is abundantly manifest in every department of knowledge and fully recognized in the attractions and repulsions in molecular mechanics, the phenomena of the repulsive energy of celestial bodies have so far been unduly obscured by the more evident principle of the attraction of gravitation.

The doctrine that the solar system, as at present constituted, was formed by the successive condensations of a nebular substance rotating about a central position, has now so much evidence in its favour that it may be affirmed to equal the best of that obtained from the geological record of the changes which, in past times, have taken place on the terrestrial globe. This doctrine has been more firmly established during recent years through the great advances

made in stellar photography, by which many of the nebulæ are visualized in various stages of evolution as right- and left-handed spirals, and clearly indicate the direction of their revolutions.[1]

That the subsequent condensations of planetary nebulæ into spherical bodies would be attended by the evolution of an amount of heat sufficient to make them vividly incandescent, is an obvious conclusion drawn directly from experimental science. It will be further evident that, after the heat of compression had attained its maximum, the self-luminous planets would ultimately become dark bodies through the radiation of their heat into free space.

It is very generally admitted that the sun, notwithstanding his vast dimensions, would, by continuous loss of heat, ultimately become a dark body like each member of the planetary system. It is also known that the internal parts of the sun are in a gaseous condition and under immense pressure. Some idea of the repulsive force exercised by this pressure may be formed from the ejection of enormous masses of incandescent gas from the surface of the sun to the height of 200,000 miles, with an estimated velocity of 166 miles per second.[2]

[1] *Celestial Photographs*, by Isaac Roberts, F.R.S., vols. i, ii, 1893, 1899.

[2] Young, *American Journal of Science*, 1871, p. 468.

Assuming the secular cooling of the sun to be continuous, the liquefaction and final solidification of his outward parts would follow in natural sequence in accordance with common experience of cooling bodies, while the central parts would remain in their primitive gaseous condition. From strict analogy, it may be justly inferred that all the planetary bodies have gone through the same stages of cooling as those outlined in the instance of the central body.

The notion that the earth and, inferentially, the other planets are solid bodies throughout, finds no support from a reasonable consideration of the constituents of the earth's crust, so far as they are accessible to observation. The late distinguished Professor of Geology in the University (Sir Joseph Prestwich), in his classical work on Chemical, Physical, and Stratigraphical Geology, has clearly demonstrated from the uplift of continental areas and mountain chains, the welling out of basaltic lavas over many thousand square miles of surface and of great thickness, that a comparatively thin crust enveloping a fluid interior is a necessary condition to satisfy the requirements of geologists and physicists. More significant still is the succession of foldings of the earth's crust and stratigraphic contortions of small curvature, both of which features

indicate a thickness of solid crust of less than twenty-five miles. How far the imprisoned gases at the centre of the earth and the aqueous vapours near the surface may have contributed respectively to produce these geological changes it is unnecessary now to discuss, but in the instance of the moon, which has neither water nor an atmosphere, the evidence of intense volcanic action manifested on its surface can only be accounted for by the ejective force of the gaseous substances in its interior, similar to that by which the incandescent gases from the surface of the sun are projected.

The fine series of photographic enlargements of the moon executed by MM. Loewy and Puiseux of the Paris Observatory show the greater part of its surface, from the equator to the poles, covered with extinct volcanoes in every stage of formation similar to those on the terrestrial globe. Some of these volcanoes are twelve thousand feet in height, with their craters upwards of forty miles in diameter, and are striking evidence of the immense repulsive force of the gases which produced them. I will mention here in passing, that Halley himself postulated the earth as a hollow sphere as the basis of his theory of the cause of the secular variation of the mariner's compass, respecting which I shall have more to say in connexion with his important

contributions to terrestrial magnetism. That a high value was set upon this view of the earth's internal constitution, and that it was intended to be handed down to posterity, is evident from his fine portrait, which adorns the apartments of the Royal Society, being embellished with a diagrammatic representation, from the Philosophical Transactions, of the terrestrial globe enclosing an inner sphere rotating with a differential motion about the same axis.

It is generally considered by astronomers that the numerous minor planets between the orbits of Mars and Jupiter are the fragments of a large planet which had formerly revolved in an orbit about the same distance from the sun as Ceres, and had subsequently been shattered by some internal convulsion. Lagrange made this hypothesis the subject of a memoir in which he determined the explosive force necessary to detach a fragment of a planet that would cause it to describe the orbit of a comet. The nebulosities of the dense atmospheres of some of these planetoids, extending to a height above their surfaces of several diameters and concealing their disks, indicate an incipient change of planetary into cometary bodies. It will now be evident without further discussion that had the exploded planet been a solid body as hard as steel it would still be revolving in its orbit, and

thus have deprived the world of an interesting chapter of astronomical science.

A review of the history of cometary astronomy brings out the remarkable fact that, while much has been written on the nature and motions of comets, few, if any, serious attempts have been made to account for their origin. The general opinion of astronomers is that these bodies are strangers to the solar system, which have been captured in the course of their lawless wanderings from other systems of the stellar universe. The principal objection to this supposition is the immense distance of the solar system from the fixed stars. The best determination of the distance of the nearest of them was made by Dr. Gill at the Cape of Good Hope in 1881, which showed that α Centauri had a parallax of 0·75″, indicating a distance of about 25 billion miles, or 9,000 million miles more distant from Neptune than that planet is from the sun. As the attraction of gravitation at the orbit of Neptune is only one forty-second millionth of that at the solar surface, the attractive force at the distance of the fixed stars may be considered a negligible quantity in determining the motions of cometary bodies having their origin in other planetary systems. Granting for the moment that comets actually belong to other

stellar systems, the problem of their origin and formation would still present itself for solution to earnest inquirers into the nature and causes of things.

The discoveries in cometary astronomy, more especially those of Schiaparelli, that the orbits of certain comets are identical with those of well-known streams of meteors, as instanced in the comets of Tempel and of Biela in relation to the November meteors, clearly point to the conclusion that the place of origin of these erratic bodies is within the confines of the solar system, and that they have, consequently, always been members of it. Moreover, all meteoric bodies, as is well known, are mechanical mixtures of elementary substances or their compounds, and further indicate them as the ejectamenta of planetary bodies.

That comets are planetary ejectamenta, principally from the larger planets, may be reasonably inferred from the prodigious force manifested by the ejections from other celestial bodies to which attention has already been directed.

The determining cause of the ejection of a comet from any planet would be found in the conjunctive attractions of one or more of their number acting upon that part of the surface from which the cometary matter was ejected. The orbital direction of a comet would be determined solely by the

position of the breach in the crust in relation to the orbital motion at the moment of discharge. The motion would be *direct* when its discharge coincided with the orbital motion of the planet, and *retrograde* when it was in the opposite direction. (Plate I.) And, according as the discharge was more or less at right angles to the plane of the planetary orbit, so would the angular direction of the comet in relation to the ecliptic be determined. The discharges from vents in high planetary latitudes would necessarily have the greatest inclination to the ecliptic. It may be observed in this connexion that some of the large craters on the moon's surface and of the terrestrial active volcanoes, Hecla and Mount Erebus, are also in high latitudes.

Halley's original conception of concentric spheres rotating within the earth, with a differential motion, is fruitful in leading to the further idea that the ejection of comets from a planet may be periodic from causes within itself, in like manner to the eleven years maximum sun spot ejection of elementary gaseous substances. For it is only necessary to assume that, after the ejection of cometary matter through the double thickness of two concentric shells, the differential motion would retard or wholly prevent the further discharge of cometary matter until the vents were again coincident.

The planet Jupiter from his vast dimensions is the most interesting member of the solar system for the study of planetary and cometary evolution. The great red spot on his surface is generally considered to be caused by luminous vapours at great depths within the globe, if not by the actual incandescent crust of that part of the planet. The great extent and permanency of this spot indicate it as the locus of one of the vents through which comets and cometary satellites have been ejected at different periods of the history of the planet.

It is now generally recognized that certain groups of periodic comets are associated in some way unknown with the larger planets respectively; the comets of short period belonging to Jupiter, as nearest to the sun, and the long period comets, of which Halley's is the most notable member, to Neptune and intermediate planets.

All the motions of periodic comets are well explained on the assumption of their moving in elliptical orbits more or less elongated, but the vast tabulated periodic times of comets supposed to move in parabolic and hyperbolic curves are necessarily ultra-speculative.

As the attraction of solar gravitation extends far beyond the orbit of Neptune, the motion of a body on the line of an open curve would ultimately be

arrested and a comet would return over the same track, approximately, with a retrograde motion as an unknown member of the solar system. Halley's comet, however, is considered to move in an elliptical orbit and has, therefore, the longest periodic time of which astronomers have certain knowledge.

As the principle of conservation holds good alike for celestial and terrestrial bodies, the moving force of comets will not exceed the attraction of gravitation beyond the limits of the solar system, and will be much less through the conversion of molar into molecular motion by friction of the discrete particles of cometary matter among themselves during the act of ejection, as also from the resistance of the medium through which they move in their orbits round the sun.

The principle of conservation, as will be obvious, will hold equally for the comets ejected from the planets of other stellar systems. Hence the absurdity of bringing cometary bodies into the solar system which contains within itself the power of evolving its own comets. Moreover, it will be further evident that this immigration notion might be extended to include the Earth and other planets as bodies from other stellar systems, captured by the Sun in their wanderings from outer space.

Jupiter, with his system of satellites, is generally

regarded as a miniature solar system formed by the successive condensations of a nebular substance surrounding the planet. The laws of attraction, moving force, and Kepler's laws have the same relations among his satellites as in the planetary system. The binary progression of the periodic times of the three adjoining major satellites, Io, Europa, and Ganymede (which are very nearly in the ratio of 1, 2, 4), indicates an orderly process of evolution similar to that of the binary progression of the planetary distances.

The erratic movements and irregular orbits of the three outer Jovian satellites recently discovered have, however, presented a new problem for solution in connexion with the nebular theory of the evolution of satellites, as it was found that the orbital motion of the outermost one was in a retrograde direction. An attempt has been made to explain the anomaly by assuming that Jupiter at an earlier period of his history performed a semi-revolution about his polar axis and that all the inner satellites turned over, in the same manner, in opposition to the orbital direction of their erratic outer member.

An insuperable objection to this ingenious hypothesis is the absence of any causal connexion between the assumed inversions of the axial motions of planets, together with their satellites and their

orbital revolutions, and, consequently, leaves untouched the problem of the retrograde orbital motion of a satellite, which is the precise object of the hypothesis to explain. The fallacy involved in the scheme will at once be apparent when applied to the orbital motion of the major planets, which are clearly independent of the positions of their axes of rotation in relation to the ecliptic. And here it may be useful to apply Newton's 'First rule of reasoning in philosophy' as laid down in the 'Principia' that, 'we are to admit no more causes of natural things than such as are both true and sufficient to explain their appearances; for Nature does nothing in vain, and more is in vain when less will serve, for Nature is pleased with simplicity, and affects not the pomp of superfluous causes.'

I have already said that when a comet is ejected from a planet opposite to the orbital motion, its direction would be retrograde to the axial rotation of the planet from which it was ejected.

The orbital velocity of Jupiter being eight miles per second, a body projected from his interior at a much greater velocity would, by the diminished attraction of the planet, conjointly with the action of solar gravity, revolve with a retrograde motion in a very irregular and much enlarged orbit in accordance with the observations. (Plate I.)

Considering the comparative minuteness of Jupiter's three outer satellites, which are estimated to be less than thirty miles in diameter, and that the orbits of J VI and J VII are both inclined at 30° to the plane of the ecliptic, and have nearly the same periodic times and distances, these small bodies are hardly entitled to rank as satellites, but may rightly be regarded as planetary ejectamenta. Nevertheless, the discovery of them is of very great importance as furnishing another indirect proof of the planetary origin of comets.

All the observations which I have made on the evolution of the Jovian satellites and cometary ejecta, are applicable alike to the Saturnian and other systems of planetary satellites. The evidence of orderly progression in the periodic times of the inner satellites of Saturn differs in one respect from that indicated by the satellites of Jupiter in similar positions, as the times of revolution of the first and third satellites are in the ratio of 1 and 2, and the times of the second and fourth are also in the same ratio, as was first pointed out by Sir John Herschel.[1]

The retrograde motions of the cometary satellites of Jupiter and Saturn afford little ground of objection to the nebular theory of planetary evo-

[1] *Outlines of Astronomy*, p. 368, 1864.

lution, as the great orbital revolutions of these small bodies round the sun are still in harmony with the theory. The objection is of the same kind, and of as little value as that which might be raised against the nebular theory, from the fact that the circumferential parts of the sun and planets rotate about their axes in contrary directions on opposite points of their diameters.

Notwithstanding that the actual surface of Jupiter is covered with dense vapours of great depth, just as the terrestrial globe at one period of its history was enveloped with an atmosphere of aqueous vapour which has since condensed to form the oceans, several facts, in addition to those advanced, indicate that the Jovian planet has a solid crust of considerable thickness.

The remarkably bright round spots which suddenly appear on the planet at irregular intervals, and have been described by Lassell and also by Dawes as having some resemblance to lunar craters,[1] indicate considerable volcanic activity below the atmospheric envelope. The eruptive matter from the Jovian craters also produces the appearance of belts on his outer surface as well as those seen on Saturn and Uranus. That these belts and bands are caused by volcanic dust ejected to great heights

[1] Monthly Notices, *Roy. Ast. Soc.*, vol. x, 1850; Ibid. vol. xviii, 1857.

from the interior parts of planetary bodies is highly probable from observations made on the great eruption of Krakatoa in 1883.[1] The ejecta from this volcano reached a height of more than thirty miles, forming a belt 20° wide on each side of the equator, and made two successive revolutions round the globe in the course of twenty-five days. The optical phenomena attending the eruption also included blue, green, and copper-coloured suns similar to the transient colours observed on the belts of Jupiter.

Turning now to Halley's important contributions to our knowledge of terrestrial magnetism. Previous to the advent of Gilbert's epoch-making book *De Magnete* in 1600, the phenomena of the earth's magnetism were limited to the directive property of a magnetized needle towards the terrestrial poles and its variation therefrom in different places. The distinguished Cambridge graduate and physician to Queen Elizabeth postulated the terrestrial globe to be a great magnet, and his important invention of the spherical loadstone, or 'terella', as he named it, enabled him to imitate very closely the directive property of the magnetic needle, especially the dip, and the cause of its variation from the equator to the poles.

[1] 'The Eruption of Krakatoa and Subsequent Phenomena.' Report of the Krakatoa Committee of the Royal Society, 1888.

As might have been expected, Gilbert's experimental demonstration of the terrestrial origin of the directive property of the magnetic needle was strongly opposed by the scholastic philosophers of his time, who supposed the seat of attraction to be the pole-star in Ursa Minor, and the cause of the variation was assigned by Cardan the mathematician to one of the stars in the tail of Ursa Major.

The speculations of these philosophers are held up to reprobation by Gilbert, who says that 'it has ever been the wont of mankind to think that earthly things are vile, and things from abroad and afar are dear to them and the object of longing. Earth the mother of all, hath these causes shut up in her recesses: all magnetic movements are to be considered with respect to her constitution, poles, equator, meridians, centre, periphery, diameter, and to the form of her whole inward substance.'

Chapters iv and v of *De Magnete* contain an exposition and defence of the diurnal rotation of the earth, which Bacon, notwithstanding the depth of much of his philosophy, declared to be extravagant, and that it could be demonstrated to be most false.[1] His strong prejudice against Gilbert's theory of terrestrial magnetism is conspicuous in several parts of the *Novum Organum* and *Advancement of*

[1] *Advancement of Learning*, Book III, Chap. 4, 1605.

Learning, and is doubtless one of the causes which contributed to the neglect and obscurity into which Gilbert's great work had fallen.

The subject of terrestrial magnetism engaged the attention of Halley from an early age, and he published his theory of the secular variation of the mariner's compass in 1683 and 1692.[1] In order to account for the change in the variation, he supposed that the terrestrial globe was a hollow shell, and that within it another shell revolved, with a differential motion about the same axis of rotation, as previously referred to. To this inner shell he assigned two magnetic poles, and to the outer one, other two poles. Halley further postulates that the two poles of the external shell are fixed in the earth, and that if the needle were wholly governed by them the variation would be always the same; but the internal sphere, having such a gradual translation of its poles, influences the needle, and directs it variously according to the result of the attractive and directive power of each pole, and, consequently, there must be a revolution of this internal ball, after which the variation will return as before. (Plate II.)

From observations of the variation Halley inferred that the direction of the internal motion was

[1] *Phil. Trans.*, xvii, 1692; *Abridgment*, iii, p. 470.

relatively westward, and, consequently, that the rotation of the inner sphere was slower than the external shell of the earth. From further observations, he concluded that the internal sphere made one revolution backwards in seven hundred years.

While the fundamental suggestion of the earth's internal motion being the cause of the secular variation of the declination is entirely due to Halley, the physical constitution and particular disposition of his internal spheres, with their magnetic poles rotating with them, are not explicable by any known principles of modern science. Electrodynamics, electro-magnetism, and the physics of the earth's crust were unexplored regions to seventeenth-century philosophers, without knowledge of which Halley's theory admitted of no further development. That Halley himself was conscious of the imperfections in his theory is seen in the truly philosophic suggestions which he made for its improvement and left, as he said, to be carried out by the industry of future ages. He finally commends all lovers of natural truth to make further observations and communicate them to the Royal Society.

In a paper which was read before this society in 1890, I have shown that all the principal phenomena of terrestrial magnetism and the secular changes in

its horizontal and vertical components, could be demonstrated on the assumption of an electro-dynamic substance (liquid or gaseous) rotating within the crust of the earth with a differential motion in the plane of the ecliptic, that is to say, at an angle of 23·5 degrees. By means of some new electro-mechanism, which I named a 'Magnetarium', the slow period of backward rotation of the internal electro-dynamic sphere required for the secular variation of the magnetic elements, on different parts of the terraqueous globe, was shown to be nine hundred and sixty years. (Plates II, III.)

Notwithstanding that two centuries have elapsed since the Royal Society published Halley's papers on the motion of the internal parts of the earth as the cause of the secular variation of the declination, his theory has made less progress during the same time than the heliocentric system of astronomy after it was revealed to the world by Copernicus.[1] In the light of modern knowledge, there is little room for doubt that the slow progress made in this department of astronomical physics is due to the survival of the primitive notions of the immobility and solidity of the terrestrial globe, and of the diurnal rotation of the celestial universe. Nevertheless, our knowledge of the cause of the varia-

[1] *De Revolutionibus Orbium Cœlestium*, Lib. VII, cap. 10, 1543.

tions of the magnetic needle has made considerable progress since the object of its attraction was located in Ursa Minor and in the tail of Ursa Major.

Modern investigators have since reduced the stellar distances of magnetic attraction by ascribing the secular variations to some unknown solar influence. Others, again, with greater courage, look for the cause in the atmosphere, and, nearer still, to some occult property of the earth's surface. But many of them, as in Gilbert's time, shrink from descending into Halley's Inferno in quest of new knowledge, and vainly endeavour to bar the passage thereto by gates of steel.

The striking similarity of the ideas of sixteenth-century philosophers in regard to stellar influences on the magnetic needle, and assigning the birth-place of comets among the stars, will be evident to all philosophic thinkers. Parallel instances of the like idiosyncrasy may also be observed in biological science with reference to the extra-terrestrial origin of organic life; astrological influences on the virtues of plants and human affairs and other notable instances, where, in the struggle for supremacy in the empire of mind, aggressive and pretentious ignorance generally secures a temporary advantage, longer or shorter, in advance of real knowledge.

Halley's theory of magnetic poles revolving in

the interior of the earth explained so many of the phenomena of the variation of the compass as to induce the British Government to fit out an expedition to search out by observations the discovery of the rule of these variations. Halley was appointed to the command of this expedition, and in the accomplishment of the object he had in view embarked in November, 1698, and traversed the Atlantic from one hemisphere to the other as far as the ice would permit him to go. Having made observations at St. Helena, Brazil, Cape Verde, Barbadoes, the Canaries, north coast of Africa, and many other latitudes, he arrived in England, after enduring great hardships, in September, 1700.

Next year he published a general chart, showing at one view the variation of the compass in all those places. This chart was the first of its kind, and is the model on which all general navigation charts have since been constructed. The original chart has been reprinted in the Greenwich Observations for 1869, under the direction of the late Astronomer Royal (Sir George B. Airy).

Although I have so far limited this discourse to natural phenomena that stand in the relation of cause and effect, or in other words, secondary causes, I am not unmindful that this great seat of learning has its foundations deeply laid in the

religious ideas and sentiments of those benefactors who have founded the various colleges of the University. That many of these ideas have since become obsolete or require modification through discoveries in natural science and in other departments of knowledge is very generally admitted, while the obligation to promote and increase the growth of true religious knowledge still remains, and will ever remain, so long as the University endures.

With some sense of personal responsibility in connexion with the new foundation in Natural and Comparative Religion recently established in the University, I have thought it well to bring forward, on this auspicious occasion, some of the later results of my recent astronomical researches which, in addition to their scientific interest, afford further direct evidence of purposive intelligence in the stellar universe.

In two papers which I read before the Manchester Literary and Philosophical Society last year,[1] it was demonstrated for the first time that the moving force of celestial bodies is as the square of the velocity, and inversely proportional to the square of the distance.

[1] *Manchester Memoirs*, vols. liii, liv, 1909; *Phil. Mag.*, vols. xviii, xix, 1909, 1910.

As the moving and attractive forces of planetary bodies are correlatively equal, and are expressed by the same numbers, the radius vector of Mercury appeared to me the most natural, as well as the most convenient unit to which the other planetary distances should be referred. A further reason for this selection was the fact that the terrestrial unit is an obvious survival of the geocentric system of the universe which has dominated science for centuries, and still retains its hold on ultra-anthropocentric writers on astronomy and astrophysics.

The change in the unit of distance also revealed a new binary progression of the planetary distances much nearer to the observations than that of Bode's law, and removed the principal grounds of objection made by some astronomers to rank the binary progression as a law of nature.

Notwithstanding the brilliant results which followed the adoption of Bode's law by independent thinkers in the discoveries of the minor planets and of Neptune, the complete isolation of the law from all physical causes, and its having no antecedent standing in the relation of a cause, admit only of a teleological interpretation, and appear to have created a strong prejudice, amounting to hostility, in the minds of eminent astronomical writers to disparage and obscure the law, ostensibly on

account of minor differences from the observations and its discordance with the distance of Neptune, but also tacitly from its teleological aspect.

The persistent intolerance and persecutions ot arrogant ecclesiasticism in former times have doubtless contributed largely to this attitude of the scientific mind towards first and final causes, which attitude has in notable instances retarded the progress both of science and religion.

On the other hand, so accustomed have some astronomers been to viewing the exact relations of Kepler's laws with the law of gravitation and the extreme refinements involved in the measurement of these relations, that their power of forming a just estimate of probabilities becomes atrophied by disuse, to the great hindrance of the science which they endeavour to advance. This habit of mind is all the more deplorable in its consequences from the fact of its being unsuspected and associated with attainments of the highest order in men occupying important positions in observatories and seats of learning, where the influence of their peculiar idiosyncrasies has made itself felt through a long course of years. The hypnotizing effect of extreme specialization on the reasoning faculties may also be seen in other departments of science, but especially in chemistry and biology, where the

evil is more pronounced in its moral consequences than in astronomy.

Bode's law, briefly stated, is as follows:—The *radii vectores*, or relative planetary distances from the sun, proceed in multiple proportions, each one after the second being double the one that precedes it (except Neptune), and by adding 0·4 to each progression we obtain a close approximation to the actual distances of the planets from the sun.

The difference between the sums of the observation distances and Bode's numbers, as I have shown, is only one fortieth part of the whole, and in the Mercurian binary progression, only one hundredth part; both these values abundantly establishing the binary progression of the planetary distances as a law of nature.

The nebular theory of the successive condensations of a gaseous substance into planetary systems in definite multiple proportions, as shown by the binary progression of planetary distances, led to my discovery in 1878 [1] of some new multiple relations among the atomic weights of well-defined families of chemical elements which clearly indicated them as products of a further condensation of the nebular substance into elementary species. So closely do

[1] 'On the Origin of Elementary Substances,' *Chemical News*, vol. xxxviii, 1878; *Manchester Memoirs*, 1887, 1895, 1904, 1907.

the theoretic atomic weights agree with those determined by experiment, that the differences between the twenty-four members of the first four positive and negative series in the tables are less than half of one per cent. of the actual determinations.

The second series of positive elements is interesting as containing the then unknown elements, helium and radium, with their atomic weights and specific gravities correctly indicated. The transformation of radium into helium is also previsedin accordance with the analogous transformations of well-known homologous series of organic compounds into their ultimates. The beautiful gradation of properties, 'in measure, weight, and number',[1] of each of the four series of elements referred to, like the binary progression of planetary distances, admits of no other than a teleological interpretation. As to the mode of existence of the Causal intelligence so clearly manifested, it is not my intention on this occasion to speak. I have elsewhere directed attention to the striking parallelism between the evolution of ideas of causation in natural science and in natural religion, and the intimate relations subsisting between them.[2]

[1] Septuagint, Wisdom, xi. 20.

[2] *Manchester Memoirs*, vol. xlviii, 1904.

Reverting now to the anomalous difference between the distance of Neptune from the binary progression, which amounts to nearly one fifth of the calculated value:—In one of my papers on the multiple proportions of the atomic weights,[1] it was laid down as a general principle of philosophic reasoning that, when a number of recurring instances was sufficient to establish the relation of cause and effect, or, in other words, the general accuracy of a law, the road to further discovery was rather in the direction of explaining the anomalous departures from it, than in challenging the truth of the law itself.

That the distance of Neptune at the genesis of its history was the first and exact term of the binary progression, is an inference justly to be drawn from the like progression observable in the distances of the other planetary bodies, and it was on this same distance (38·4) that Adams, in 1845, based his first determination of the then unknown planet.

The Astronomer Royal (Sir George B. Airy), in his historical review of the circumstances connected with the discovery of Neptune, says that 'if the mathematicians, whose labours I have described, had not adopted Bode's law of distances (a law for

[1] *Manchester Memoirs*, vol. xxxix, 1895.

which no physical theory of the rudest kind has ever been suggested), they would never have arrived at the elements of the orbit',[1] or, in other words, would never have discovered Neptune.

The most probable as well as the most obvious cause of the anomalous minus difference in the binary progression of the distance of Neptune is the outermost position of the planet in relation to the other members of the system; with the consequent conjoint attractions of all the planets to contract continuously and permanently his radius vector to the amount shown in the observations. The large amount of this contraction is strong presumptive evidence against the existence of a planet beyond the orbit of Neptune.

A further consequence of the outermost position of Neptune is the small amount of the eccentricity of his orbit, 0·009, or nearly six times less than the eccentricities of Uranus, Saturn, and Jupiter, which, excepting Venus, 0·007, is the nearest approach to a circular orbit of any member of the system.

It is not a little remarkable that the inevitable effect of the outermost position of a planet to contract continuously its radius vector has never presented itself to Lagrange, Laplace, and other writers on celestial mechanics who have elaborated the

[1] *Proc. Roy. Astron. Soc.*, 1846; *Phil. Mag.* (3), vol. xxix, 1846.

doctrine of the absolute stability of the solar system.

The conjoint attractions of all the planets upon Neptune to contract his radius vector may be easily demonstrated by means of a simple diagram, or by arranging a number of coins on a table in different positions and distances around a central object to represent the solar system. The demonstration may also be more elegantly given on the ordinary planetarium. (Plate IV.)

Assuming the future contraction of the orbit of Neptune to be continuous, his radius vector will ultimately coincide with that of Uranus, when the two bodies would either revolve together about their common centre of gravity in the same orbit, or coalesce to form a self-luminous planet, when the same operation would be repeated in succession with other members of the system.

It is further evident that all the planets would ultimately coalesce to form one or more self-luminous bodies revolving round the sun, as one of the binary or ternary systems of stars, of which upwards of ten thousand have been discovered and catalogued during the last century.

The probability that the ultimate transformation of the solar system will be brought about by the means, and in the order set forth (but at a time too

remote for our present means of calculation), derives further support from the fact that one of the stars of long recognized binary systems is itself a close double star, revolving about its common centre of gravity, as instanced in μ Herculis and γ Andromedæ.

The last instance of ejective repulsion which I shall bring forward is the explosive energy manifested during the outbursts of variable stars of the type of T Coronæ and Nova Aurigæ. The most rational explanation offered by astronomers of these impressive phenomena of celestial dynamics, is that two stellar bodies had approached so closely together as to induce disruptive action, or were brought into actual collision; and released from enormous pressure vast masses of incandescent gases from their internal parts, immensely greater, but similar in kind to solar eruptions.[1]

To summarize:—(1) In the law of the binary progression of the planetary distances—shining forth alone in the formless void—and in the multiple proportions of the atomic weights, we have the primordial expressions of intelligent purpose in the universe revealed directly to the mind of man, and destined hereafter to become part of the broad cosmological foundation upon which the natural

[1] Sir William Huggins, *Collected Scientific Papers*, p. 252, 1909.

development of religious ideas will ultimately rest; (2) that as planetary systems have been evolved in regular order from a nebular substance, so their transformations will proceed, in like order, to form the numerous binary and other revolving systems observed in the immensity of the stellar universe.

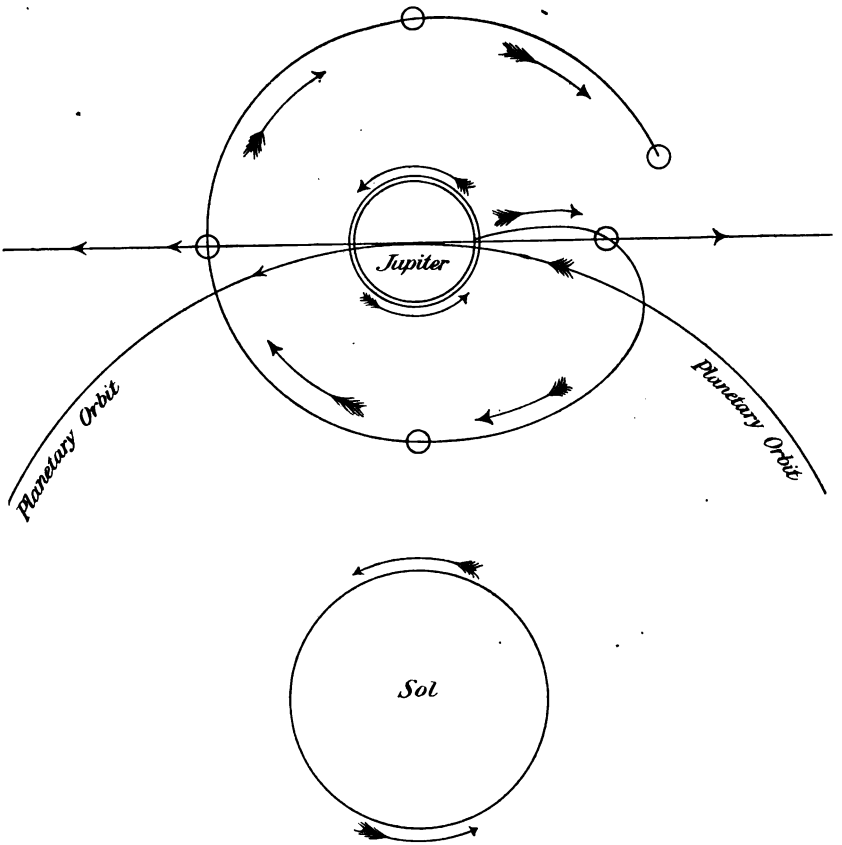
In following up to their ultimate issue these views of the transformation of planetary and stellar systems, some minds may naturally shrink from forming conclusions involving, apparently, the annihilation of man as a sentient being. But there are abundant means of knowing that such nirvanian conclusions are not a necessary consequence of the dissolution of these systems. For just as the conscious intelligence of man perceives the workings of purposive intelligence animating the universe—cosmos and microcosmos—through countless ages; so the well-grounded conviction is established in his mind that, whatever happens, the principle of conscious intelligence within himself is of the same nature as that manifested in the universe around him, and is, therefore, immortal and eternal.

Another brilliant ornament of this University, whose noble hymns enter deeply into the religious life of English-speaking peoples throughout the world, has expressed man's ultimate relations to

the cosmos in the striking language with which I shall now conclude this discourse:—

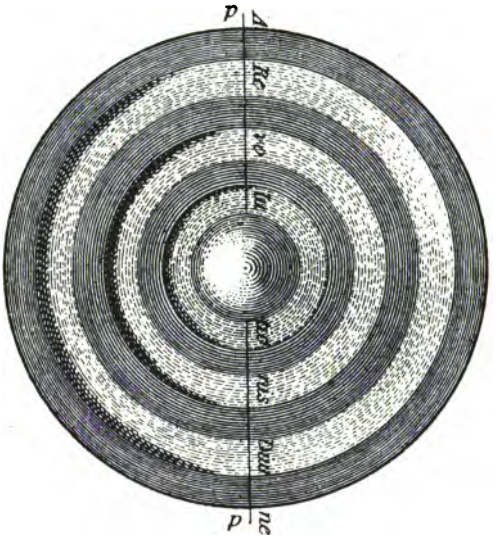
> The stars shall fade away, the sun himself
> Grow dim with age, and nature sink in years;
> But thou shalt flourish in immortal youth,
> Unhurt amidst the war of elements,
> The wrecks of matter, and the crush of worlds.

ADDISON'S *Cato*.

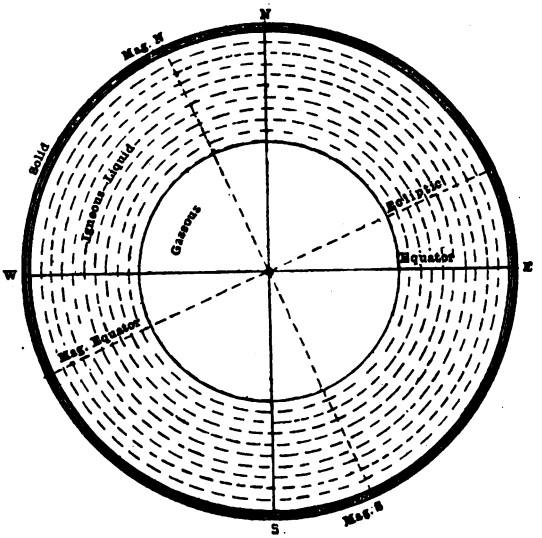


COMETARY SATELLITES WITH RETROGRADE MOTION.

HALLEY. 1692.

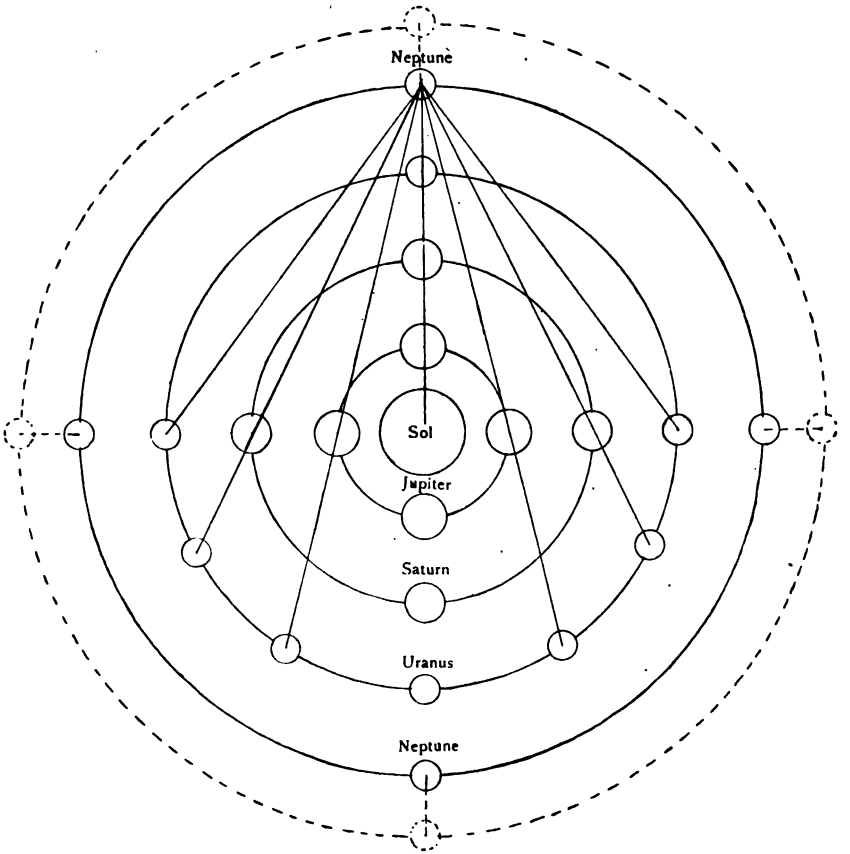


WILDE. 1890.



DIFFERENTIAL ROTATION AND GENERAL CONSTITUTION OF THE INTERNAL PARTS OF THE TERRESTRIAL GLOBE.

MAGNETARIUM, FOR DEMONSTRATING THE DIFFERENTIAL ROTATION OF THE INTERNAL PARTS OF THE EARTH AND THE RESULTANT PHENOMENA OF TERRESTRIAL MAGNETISM ON ITS SURFACE.



DIAGRAMMATIC REPRESENTATION OF THE CONTRACTION OF THE RADIUS VECTOR OF NEPTUNE.

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